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Artisanal Marine Fisheries and Climate Change in the Region of Lima, Peru

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1. INTRODUCTION

We are living in a time of climate change, and no part of the ocean is unaffected by human influence; in particular, some areas close to population centers, are greatly affected by multiple pressures (Vierros, 2017). According to FAO (2018) and Perrings (2016), more than two thirds of all fish stocks are being exploited at or beyond their maximum sustainable production levels. The declining health of the oceans has consequences for people's livelihoods and the entire economy, and it is the poorest communities dependent on maritime resources that tend to be affected the most.

In 2016, world marine fishing production was 79.3 million tons (FAO, 2018). The FAO projects that by 2050, climate change will have altered the productivity of many of the planet’s marine and freshwater fisheries, affecting the livelihoods of millions of the world's poorest people. The impacts are associated with changes in water temperature, pH levels, and ocean circulation patterns, resulting in rising sea levels, severe storms, and heavy rainfall while causing changes of distribution and productivity among fish species (Barange *et al*., 2018). In turn, fish landings reflect the oceans’ productive capacity, as well as management decisions made in response to changes thereto.

In Peru, artisanal marine fishery in the 2004-2017 period represented an annual average of 19 percent of total landings. This is important because it the fishery products it provides for human consumption contributes to food security. This artisanal fishery is also a source of employment and income. However, artisanal fishermen are vulnerable both economically and at risk from climate change. According to IMARPE (2018) this activity extends along the coast, making use of an arts and extraction methods variety depending on the target species, seasonality, type of vessel and the innate ingenuity of the artisanal fisherman.

The most notable factors of climatic variability in the Southeast Pacific fisheries are the ENSO (El Niño Southern Oscillation), the DOP (Pacific Decadal Oscillation) and the SVP (Secular Variability of the Pacific). The processes of population dynamics of resources, such as recruitment, growth, natural and fishing mortality, are permanently affected, at different intensities and scalar frequencies (Espino and Yamashiro, 2012).

The proportion of anchoveta landings in the Peruvian fishery has varied from a third in the 80's to about 90% in the 2000’s. Anchoveta landings predominated in the 60’s, first half of the 70’s, 90’s and 2000’s. However, the sardine stood out in the landings of the 80’s (Espino & Yamashiro, 2012).

Small-scale fishers are exposed to the direct repercussions of climate change because, generally, they live in settlements close to the sea; properties and infrastructure run the risk of damage from direct destructive factors such as rising sea levels and storms of increasing frequency and intensity (Daw *et al.*, 2009). This also compounds the hazards involved in maritime activities, while changes in climate patterns alter fishing practices founded on traditional knowledge of local weather conditions and ocean currents.

Internationally, Lan *et al.* (2016) analyze unique long-term records of gray mullet catch rates in the Taiwan Strait, finding that they correspond fairly well with the Pacific Decadal Oscillation, the Oceanic Niño Index, and rising sea surface temperatures caused by climate change, which might have affected the species' abundance and migration behavior in the strait.

According to The IPCC, climatic threats in the fishing sector are variations in the Sea Surface Temperature (SST); increases in the average sea level (which the Ministry of the Environment predicts will rise by between 60 and 80 cm by 2100); and extreme climatic events such as flooding, intense rainfalls, landslides, mudslides, and rogue waves.

According to Nunoo *et al.* (2016), Ghana's fisheries sector plays an important role in socioeconomic development linked to food security, employment, GDP, and foreign exchange, but there is a dependence on fishery products for livelihood and poverty reduction similar to Peru. Artisanal fishers employ gear such as purse seine, gill, and lobster nets.

According to Øistein and Hoel (2013), climate change and variability causes changes to marine ecosystems, and to the growth and geographical distribution of live marine resources. Successful management of live marine resources will depend on the capacity of management regimes to be adaptable and flexible. While climate change can manifest itself in the geographical distribution of fish stocks and disturbed ecosystems, the changes are not only biological but also political, in terms of the management of opportunities to utilize live marine resources.

The Humboldt Current System (HCS) is the world's most productive marine ecosystem in terms of fish caught, and climate is considered to be the most important driving factor (Barange *et al.*, 2018: 349). On average, 9.35 million tons of marine fish, mollusks, and crustaceans were landed each year in Chile and Peru over the period 2005-2015, though there was a notable downward trend. The two main species landed were the Peruvian anchoveta (Engraulis ringens) and the Chilean jack mackerel (Trachurus murphyi). The region of northern and central Peru accounted for 75 percent of the total catch, while southern Peru and northern Chile represented nearly 20 percent. Climate change could cause a shift in the HCS away from favoring fish productivity, while El Niño events could increase in frequency (Barange *et al*., 2018).

Porobic *et al.* (2019) study a vulnerable marine ecosystem located off the central Chilean coast, formed by the Juan Fernández Archipelago and a group of seamounts. In this system, two fleets have historically operated: a long-term artisanal coastal fishery associated with the archipelago and centered primarily on lobster; and an industrial demersal finfish fishery operating on the seamounts, presently considered overexploited.

The seasonal variability in the Peruvian sea ecosystem is due to southeast trade winds that are weak in summer and strong in winter, and unusually warm periods known as "El Niño" cause many species, particularly the Peruvian anchoveta, to migrate to other latitudes; warm and cold divergent ocean currents make the Peruvian sea one of the most biodiverse and productive in the world (Martín *et al*., 2014).

In February and March 2017 the El Niño phenomenon located off the coast of Peru caused heavy rains in the northern part of the country, and due to altered oceanographic conditions the Humboldt current (ascent of very cold deep waters) halted, sea temperatures increased from an average of 16–17 ° C up to 28 ° C (Kluger *et al*., 2018).

The focus on climate change and variation is justified by the fact that economic activities in or around the oceans have increased exponentially (Vierros, 2017), and this, coupled with climate change and variability, threatens the regeneration of marine resources while also reducing the volume of fish landed in the ports of Lima region and impacting the livelihoods of artisanal fishers.

The research topic is important because climate change affects the health of the oceans and, thus, the extraction of marine resources; as such, policymakers in the fisheries sector implement adaptation measures for the sustainability of both marine biodiversity and the standard of living of artisanal fishers from the Lima region and Peru.

Our aim in this study is to analyze the effects of climate change on the artisanal marine fishing economy in the Lima region, and to explore climate change adaptation measures.

2. METHODS

Spatial and temporal scope:

The study focuses on artisanal marine fishery resources in the region of Lima, Peru, and how they are affected by climate change.

Material:

Information centers and documentation: Statistics from the Ministry of the Environment (MINAM) Ministry of Production (PRODUCE), National Institute of Statistics and Informatics (INEI), Peruvian Institute of the Sea (IMARPE).

Data collection techniques:

Secondary information compiled from the Statistical Yearbooks of Fisheries for the period 2013-2017 (PRODUCE), the Statistical Compendium of Lima-Provinces 2014 (INEI) and, from IMARPE about artisanal fisheries and climate change in the region of Lima (2004-

2017). Primary information using a questionnaire addressed to artisanal fishermen framed to the largest annual landing of marine resources by port in the Lima region that turned out to be the port of Chancay (it does not consider the ports of Lima Metropolitana) in the study period. In July 2017, after the 2017 summer El Niño event, a survey was conducted to the fishermen affiliated with the artisanal fishermen's union of the Chancay port who attended the assembly of the union in the same port. The questionnaire was answered by 91 fishermen. The short questionnaire has two parts. The first part deals with gender, age and educational level. And in the second part, the knowledge of the climate change impact on fisheries is addressed in order to investigate the recommendations and adaptation measures proposed by the fishermen themselves. An interview was also conducted with the president of the artisanal fishermen's union of the Chancay port, Lima region (2018).

Procedure:

First, we review the characteristics of the marine economy in the face of climate change, from the perspective of economic agents in the region and in terms of marine resources landed. Second, we analyze the relationship between climate change and the exploitation of artisanal marine fisheries, according to landings of marine fish for direct human consumption. Third, a short survey questionnaire was designed and applied to artisanal fishermen in the Chancay port, Lima region in July 2017 in order to learn about the damage caused by both climate change and the El Niño phenomenon and the actions they suggest to adapt to climate change. Fourth, we explore the climate change adaptation measures for artisanal fisheries in the region of Lima.

3. RESULTS AND DISCUSSION

In this section, we present the characteristics of the economic activity of marine fishery in the main ports of the Lima region considering the landings of marine resources for direct human consumption (artisanal fishery) and for indirect human consumption (industrial fishery); we look at SST behavior in the context of climate change and then we apply regressions to see the economic interrelationships of the fishing landings, the fishing gross added value and the fishing effort with the SST; we also analyze the effect of the SST variability on the scarcity of marine resources and the volatility of the fishing gross added value. Data on catch levels and SST, fishing effort, gross fishing value added are used.

3.1. Climate Change and Artisanal Marine Fishery Catches

The Peruvian Institute of the Sea (IMARPE), assigned to the Ministry of Production, conducts research into the Peruvian sea and its live resources, advises the state on its decision-making about the reasonable use of fisheries resources and conservation of the marine environment, and has contributed to the monitoring of artisanal fisheries for over twenty years (Guevara-Carrasco & Bertrand, 2017).

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Gill nets, sometimes known locally as "curtain nets," are found throughout the central part of the country, in fishing ports such as Salaverry, Chimbote, Huacho, Chancay, Ancón, Callao, Chorrillos, Pucusana, and San Andrés. These nets are used on small vessels with a hold capacity of between 0.5 and two tons. Crew sizes are small (two to three fishers) and vessels undertake short trips (twelve hours on average), during which they catch a variety of species such as silverside, striped mullet, among others, but in low volumes (between 25 and 150 kilograms per trip) (Guevara-Carrasco & Bertrand, 2017).

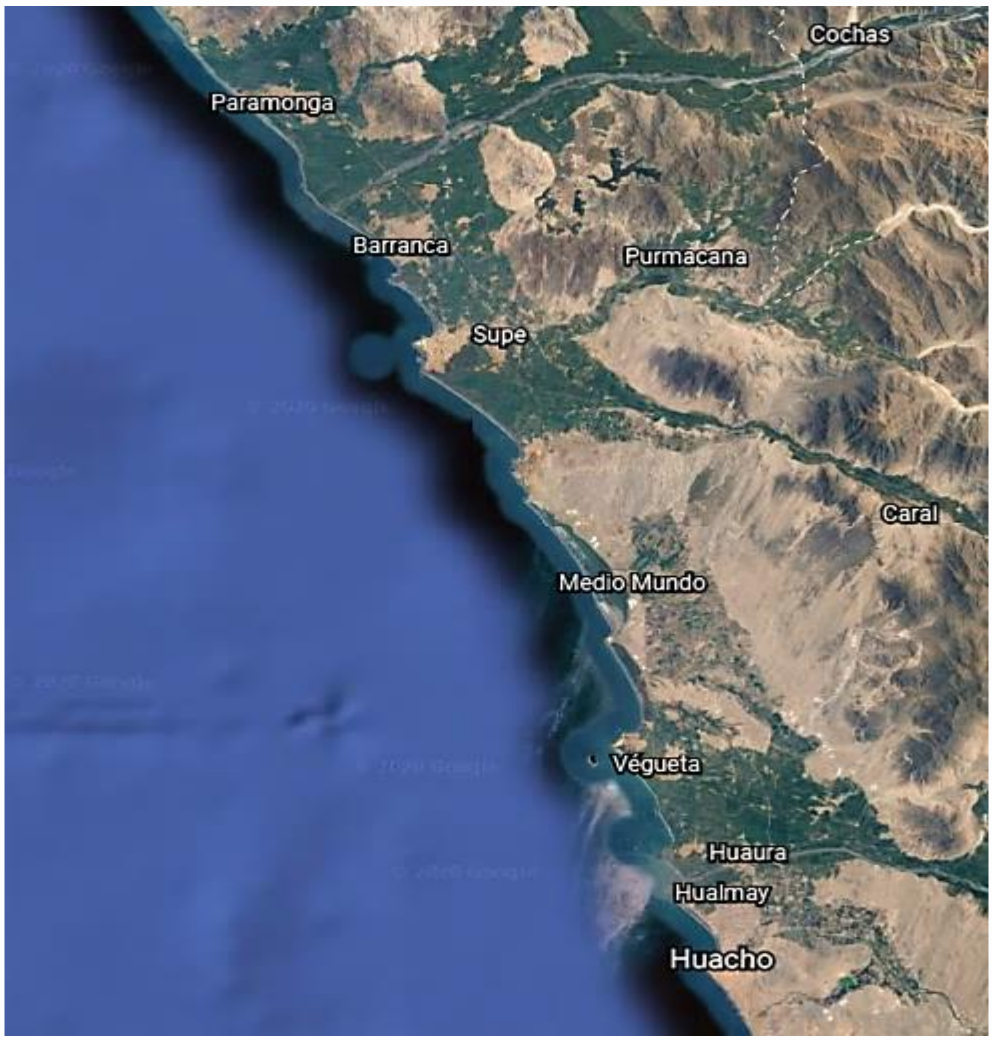

Figure 1. Ports in the Lima region

The main ports in the region of Lima are Végueta, Huacho/Carquín, Chancay, and Supe.

Table 1. Lima region: Landings of marine resources by port, 2005-2017
(Metric tons)

Puerto	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total Perú	**9,353,306**	**6,983,463**	**7,178,699**	**7,362,907**	**6,874,404**	**4,221,093**	**8,211,718**	**4,807,567**	**5,948,567**	**3,530,654**	**4,863,030**	**3,806,672**	**4,201,174**
Végueta	441,318	220,164	217,457	247,413	240,389	34,404	301,715	80,756	237,229	117,701	212,602	133,199	102,191
Huacho/Carquín	236,233	152,421	154,906	183,810	135,397	44,860	237,763	85,851	158,680	99,037	148,008	116,935	76,045
Chancay	788,198	496,253	432,570	425,423	378,326	196,273	703,495	290,569	463,987	210,889	316,069	165,949	189,321
Supe-Puerto	632,956	356,334	337,642	391,531	359,275	94,924	433,383	112,709	327,687	113,831	199,921	165,042	132,635
Región Lima	**2,098,705**	**1,225,172**	**1,142,575**	**1,248,177**	**1,113,387**	**370,461**	**1,676,356**	**569,885**	**1,187,583**	**541,458**	**876,600**	**581,125**	**500,192**

Source: INEI. Compendio Estadístico de Lima Provincias 2014 Anuario Estadístico 2013-2017
Compiled by the author.

The Lima port at which the highest number of landings were recorded over the period of study (2005-2017) was Chancay.

Table 2. Lima region: Landings of marine resources for direct human consumption by port, 2004-2017
(Metric tons)

Port	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Total Peru	**763,645**	**724,602**	**1,087,920**	**1,092,670**	**1,196,433**	**1,043,549**	**890,681**	**1,209,465**	**1,104,757**	**1,182,874**	**1,264,761**	**1,168,601**	**1,020,022**	**991,828**	
Végueta	9,099	2,132	3,243	3,476	6,780	6,996	645	7,887	5,059	10,401	7,109	406	198	346	
Huacho/Carquín	779	7,942	12,394	10,555	11,138	9,430	7,739	37,945	21,632	33,835	21,575	5,210	20,734	5,957	
Chancay	392	1,741	2,332	2,633	1,938	1,897	1,334	2,060	2,056	1,734	2,250	1,552	1,663	3,164	
Supe-Puerto	1,055	3,805	4,794	1,878	2,401	2,511	1,170	4,239	2,600	6,452	3,042	1,756	2,187	1,281	
Lima region	11,325	15,620	22,763	18,542	22,257	20,834	10,888	52,131	31,347	52,422	33,976	8,924	24,782	10,748	
% Lima region/Total Peru	1.5	2.2	2.1	1.7	1.9	2.0	1.2	4.3	2.8	4.4	2.7	0.8	2.4	1.1	Avg. 2.2 %

Source: PRODUCE. Anuario Estadístico Pesquero 2016-2017; Dirección General de Políticas y Desarrollo Pesquero.

Compiled by the author.

Assuming that artisanal fisheries meet the demand for direct human consumption, artisanal marine fishery landings accounted for an average of 2.2 percent of Peru's total annual landings over the period 2004-2017.

Table 3. Lima region: Landing of marine resources for indirect human consumption by port, 2004 – 2017
(Million Metric tons)

Port	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total Peru	**8.81**	**8.63**	**5.90**	**6.09**	**6.17**	**5.83**	**3-33**	**7.00**	**3.70**	**4.77**	**2.27**	**3.69**	**2.79**	**3.21**
Végueta	0.40	0.44	0.22	0.21	0.24	0.23	0.34	0.29	0.08	0.23	0.11	0.21	0.13	0.10
Huacho/Carquín	0.19	0.23	0.14	0.14	0.17	0.12	0.04	0,20	0.06	0.12	0.08	0.14	0.10	0.07
Chancay	0.75	0.79	0.49	0.43	0.42	0.38	0.19	0.70	0.29	0.46	0.21	0.31	0.16	0.19
Supe-Puerto	0.51	0.63	0.35	0.34	0.39	0.36	0.09	0.43	0.11	0.32	0.11	0.20	0.16	0.13
Lima region	**1.85**	**2.08**	**1.20**	**1.12**	**1.23**	**1.08**	**0.36**	**1.62**	**0.54**	**1.14**	**0.51**	**0.87**	**0.56**	**0.49**

% Lima region / Total Peru	20.9	24.1	20.4	18.5	19.9	18.4	10.8	23.2	14.6	23.8	22.4	23.5	20.0	15.3	Avg. 19.7 %

Source: INEI. Compendio Estadístico de Lima Provincias 2014
PRODUCE. Anuario Estadístico Pesquero 2017
Compiled by the author.

Artisanal fishery in the marine space is the extractive activity carried out by artisanal natural or legal persons without or with the use of boats up to 32.6 cubic meters of hold capacity and up to 15 meters in length and, with predominance of manual labor (regulation of the General Fisheries Law, Supreme Decree No. 012-2001). Its product is mainly intended for direct human consumption (DHC). The zone between zero and five nautical miles is reserved exclusively for DHC, including the anchoveta (*Engraulis ringens*) and the white anchovy (*Anchoa Nasus*).

Industrial fishery extracts marine resources mainly anchoveta for indirect human consumption using vessels larger than 32.6 cubic meters of warehouse capacity and supplies inputs to the fishmeal, oil and canned fish industries. Anchoveta fishing is carried out along the Peruvian coast using boats with purse seines, with a mesh size of ½ inch (13 mm) and operates outside the 5 nautical miles of the coastline. It is characterized by having technological support for the location, extraction, processing and conservation of fish.

The average landing of industrial marine fishing for indirect consumption in the Lima region is 19.7 percent of Peru's total annual industrial marine fishery landings over the period 2004-2017 (Table 3).

Table 4. Lima region: Sea surface temperature (SST), 2004-2017
(degrees Celsius)

Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Average annual temperature	16.26	16.23	16.74	15.73	16.67	16.98	17.61	16.12	16.94	15.44	16.99	17.87	17.39	17.13

Source: INEI. Compendio Estadístico de Lima Provincias 2014

IMARPE. Huacho Laboratory 2014-2017

Compiled by the author

There is evidence of variability in the SST over the period 2004-2017, with a high annual average of 17.6 degrees Celsius in 2010 and 17.9 degrees in 2015. In addition, in the presence of the El Niño phenomenon, during the summer 2017, the SST rose to 21 ° C monthly in February 2017, showing lower landings for direct and indirect human consumption in 2017 (tables 2-3).

Table 5. Correlations: SST-marine resources by port, Lima region, 2004-2017

		Landings of marine resources, Vegueta port	Landings of marine resources, Huacho/Carquín port	Landings of marine resources, Chancay port	Landings of marine resources, Supe port
SST, Huacho Lab	Pearson's correlation	-0.562*	-0.600*	-0.654*	-0.629*
	Sig. (bilateral)	0.036	0.023	0.011	0.016
	N	14	14	14	14

*The correlation is significant at the 0.05 level (bilateral)

Table 6. Correlations: SST-marine resources for direct human consumption, Lima region ports, 2004-2017

		Marine resource landings for direct human consumption, Végueta	Marine resource landings for direct human consumption, Huacho/Carquín	Marine resource landings for direct human consumption, Chancay	Marine resource landings for direct human consumption, Supe
SST, Huacho Lab.	Pearson's correlation	-0.653*	-0.394	-0.043	-0.569*
	Sig. (bilateral)	0.011	0.164	0.885	0.034
	N	14	14	14	14

*The correlation is significant at the 0.05 level (bilateral)

For the period 2004-2017, it can be seen that the higher the SST, the lower the catch volume, measured by way of the decrease in landings of marine resources at the ports of Lima region, significant at five percent (Table 5).

Considering artisanal fishing activity in terms of the landings of marine resources for direct human consumption, it is found that the SST is related negatively to such landings at ports in the Lima region, although this relationship is not significant for the ports of Huacho / Carquín and Chancay (Table 6).

In the first quarter of 2018, Huacho artisanal fishing made the greatest effort directed to curtain type fishing gear with 393 trips and a catch per unit of effort (CPUE) of 218.27 kg / trip with fishing ("twf"). The fishing areas of the artisanal fleet that directed its effort to the anchoveta, were located near the coast between Carquín-Huacho and Chancay within one nautical mile away (IMARPE, 2018). The industrial fishery made 895 trips, and an average catch per unit of effort (CPUE) of 72.4 t / twf.

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Table 7. Correlations: SST-marine resources for indirect human consumption, Lima region ports, 2004-2017

		Marine resource landings for indirect human consumption, Végueta	Marine resource landings for indirect human consumption, Huacho/Carquín	Marine resource landings for indirect human consumption, Chancay	Marine resource landings for indirect human consumption, Supe
SST, Huacho Lab.	Pearson's correlation	-0.551*	-0.536*	-0.653*	-0.626*
	Sig. (bilateral)	0.041	0.048	0.011	0.017
	N	14	14	14	14

*The correlation is significant at the 0.05 level (bilateral)

In the Lima region ports, industrial marine fishery landing (mainly anchoveta species) is negatively related to the SST at a 5% level of significance (table 7).

Table 8. Regression: SST-marine resources, ports of the Lima region, 2004-2017

Port	Model	B coefficients	Typ. error	t	Sig.
Chancay	(Constant)	3705418.087	1099578.748	3.370	0.006
	SST, Huacho Lab.	-196777.596	65705.359	-2.995	0.011
Végueta	(Constant)	1791800.130	670898.263	2.671	0.020
	SST, Huacho Lab.	-94349.230	40089.545	-2.353	0.036
Huacho/Carquín	(Constant)	956541.090	313061.238	3.055	0.010
	SST, Huacho Lab.	-48595.063	18706.983	-2.598	0.023
Supe	(Constant)	2789843.133	889431.260	3.137	0.009
	SST, Huacho Lab.	-149053.173	53147.990	-2.804	0.016

a. Dependent variable: Landings of marine resources by port, MT

It can also be seen that the increase in the SST has a significant association ($\alpha = 0.05$) with the reduction in landings of marine resources at the port of Chancay (table 8). Likewise, the SST has resulted in smaller landings of fish at the ports of Végueta, Huacho/Carquín, and Supe (table 8).

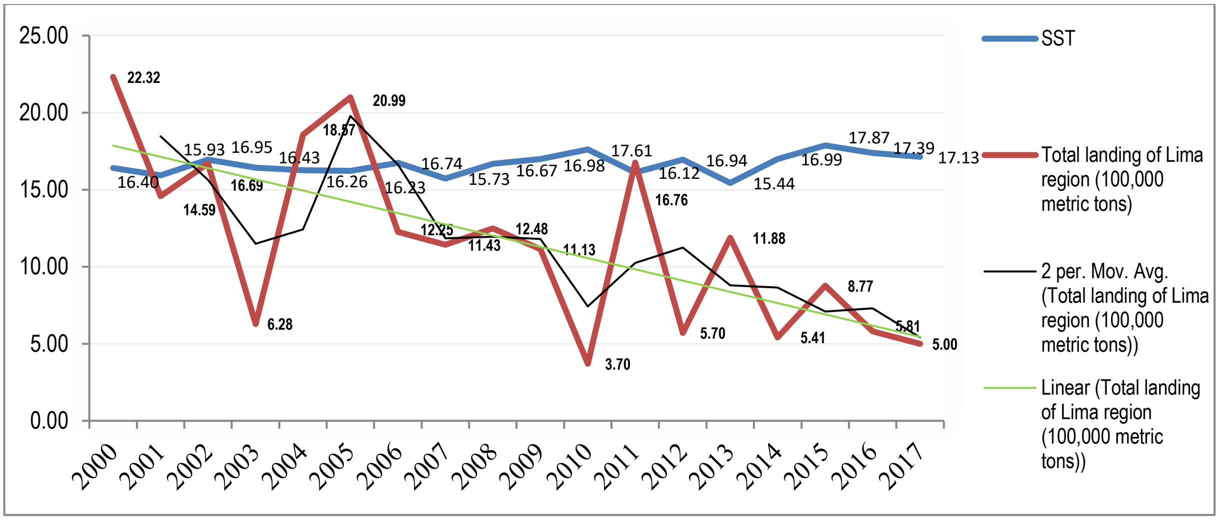

Figure 2. Variability of SST - Landing of marine resources, Lima region ports 2000 - 2017

Table 9. Regression: SST - Landing of marine resources, Lima region ports 2000- 2017

Coefficients[a]

Model	Non-standardized coefficients		Typified coefficients	t	Sig.
	B	Typ. error	Beta		
(Constant)	91.171	31.210		2.921	0.010
SST, Huacho Lab.	-4.774	1.872	-0.538	-2.550	0.021

a. Dependent variable: Total landing of the Lima region (100,000 metric tons) 2000-2017

The variability of SST affects the landing of marine fisheries in the Lima region (Figure 2, Table 9).

Moreover, artisanal fishers are also vulnerable to climate variability. In an October 2018 interview, the president of the Chancay union of artisanal fishers stated that the port had experienced cooler seawater and a sharp decrease in fish stocks. This marked a contrast to the El Niño phenomenon of summer 2017, when it was rises in temperature that caused a drop in fish levels. This variability is explained because the SST of summer 2018 registered cold conditions, characteristics of the La Niña event that intensified with the seasonality, varying from 16 to 19 ° C along the Peruvian coast from June to October; as of November, the SST increased due to the entry of warm equatorial surface waters, very coastal isotherms of 20 ° C and 24 ° C (IMARPE, 2019: 23) that expanded to the Lima region ports.

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Table 10. Regression: SST - Gross Value Added of Total Fishing (Thousands of soles), Lima 2007- 2017

Coefficients[a]

Model		Non-standardized coefficients		Typified coefficients	t	Sig.
		B	Typ. Error	Beta		
1	(Constant)	2304.809	773.353		2.980	0.015
	SST, Huacho Lab.	-113.439	45.972	-0.635	2.468	0.036

a. Dependent variable: Fishing Gross Value Added, Thousands of soles (at Constant Prices of 2007), Lima.

The SST was found to influence the Gross Value Added of fishing at a 5% level of significance (table 10). In addition, the average gross value added from 2007-2017 fishing in Lima is 398,305 soles (US $ 117,148 dollars) with a standard deviation of 136,227 soles (US $ 40,067). Therefore, the variability of the SST, in economic terms, generates volatility of the gross value added in the fishing sector.

Table 11. Correlations: SST, Fishing effort, Value of fishing at 2007 constant prices, Lima

		Log (No. of boat trips purse seine fleet - Fishing effort)	Anchoveta landing for fishmeal, in region Lima ports, 2004-2017	Gross Value Added of Total Fishing, Thousands of soles (at Constant Prices of 2007), Lima 2007-2017
SST, Huacho Lab	Pearson's correlation	-0.630*	-0.626*	-0.635*
	Sig. (bilateral)	0.038	0.017	0.036
	N	11	14	11
Log (No. of boat trips purse seine fleet - Fishing effort)	Pearson's correlation	1	0.629*	0.509
	Sig. (bilateral)		0.038	0.198
	N	11	11	8
Anchoveta landing for fishmeal, in region Lima ports, 2004-2017	Pearson's correlation	0.629*	1	0.984**
	Sig. (bilateral)	0.038		0.000
	N	11	14	11

*The correlation is significant at the 0.05 level (bilateral)
**. The correlation is significant at the 0.01 level (bilateral).

It is shown that the higher the SST, lower fishing effort and lower fishing value in constant soles, that is, significant economic losses. In addition, the greater the fishing effort, the greater the anchoveta landing for fishmeal, therefore, the positive correlation between anchoveta catch for fishmeal and the value added of fishing is significant at one percent. On the other hand, there is a significant negative correlation between the SST and the unloading of anchoveta for fishmeal (table 11).

It was found that the greater the fishing effort, the marine fishery extraction such as the anchoveta for fishmeal increases and therefore the gross value added (GVA) of fishing increases, but these economic variables are negatively related to the SST climatic variable. This would imply that an increase in SST decreases anchoveta landings for DHC and the GVA of artisanal fishing.

3.2. Climate Change Adaptation in Fisheries and Challenges for Implementation

The main economic effect of climate change for artisanal fishermen is the fish scarcity and therefore the loss of economic income.

According to PRODUCE (2016b), the El Niño phenomenon decreases the productivity of marine resources such as anchoveta.

The added value of artisanal fishing is strengthened, for example, through dried anchoveta in the consumption of traditional food (Zavala et al., 2019) and technological innovation of cold systems on board in fishing vessels. To improve the adaptability of artisanal fishers, PRODUCE held workshops on promotion and implementation of formalization activities, creation of microenterprises, processing and marketing.

Zavala et al. (2019) recommend evaluating species with better adaptive capacity than anchoveta, as has happened in past warm periods and incorporating bio-economic modeling in future quantitative scenarios of fisheries vulnerability. In a context of sustainable development, climate change adaptation measures must be framed within development plans and programs at both local, regional and central government levels; and in their execution, the productive chain efficiency, the diversification of fisheries for direct human consumption and product quality should be prioritized.

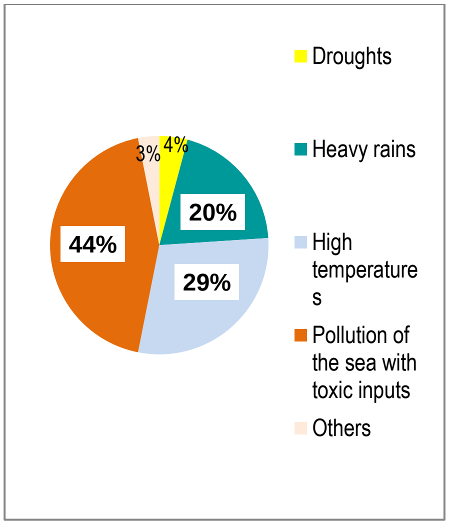
For Barange *et al.* (2018) transformational adaptation implies fundamental changes to the system, often at greater scales and with greater effort than incremental adaptation (based on the expansion of existing actions), and can include migrating or changing livelihoods, as well as governance adaptation. The adaptive capacity approach can be designed to produce parallel benefits in terms of poverty reduction, food security, and climate adaptation (Barange *et al*., 2018: 573). The aim of adaptation is to increase resilience and reduce climate change vulnerability, according to the Intergovernmental Panel on Climate Change (IPCC).

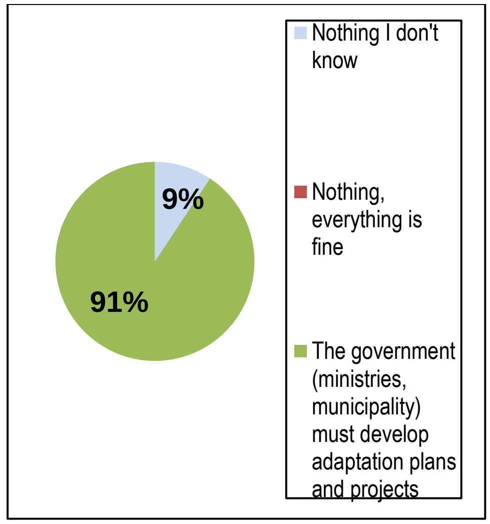
According to Huq (2016) within the ecosystem-based adaptation (EbA) approach, there is a lack of attention paid in the literature to "adaptive institutions for EbA." The term “adaptive institutions” varies across different disciplines of knowledge, and can relate to adaptive governance for natural hazards, adaptive natural-resource management and co-management, socio-ecological system governance, and institutional adaptive capacity to climate change. Thus, a multidisciplinary and multiagency approach is imperative.

EbA takes into account the following principles: 1) A working approach involving institutions and multiple stakeholders to strengthen adaptation efforts and enhance community and ecosystem resilience; 2) flexible management structures that allow local institutions to integrate complexities and adapt to future adaptation needs by way of resource management; 3) fostering knowledge generation, management, and diffusion for effective EbA implementation and to tackle the uncertainties of climate models.

The SST (°C) was used to analyze the impact of the climate on small pelagic fish populations in the Southern Humboldt Current Ecosystem (Canales *et al*., 2020). They found that the dynamics of anchovy populations located off northern Chile were driven by endogenous components and by the effects of climate, fishing and the climate-fishing interaction, and indicate that negative SST anomalies could favor the recruitment of the common sardine. The approach provides a framework for integrating climate variability into the population dynamics of these species and moving towards an ecosystem approach to fisheries management (Canales et al., 2020).

In July 2017, after the 2017 El Niño summer event, a survey was administered to 91 artisanal fishermen from the Lima region (Chancay port) to learn about the most damaging effect of climate change in their fishing zone and the actions they recommend to face the impact of the El Niño phenomenon in fishery sector. It was found that 94% of the respondents are male, 55% are over 50 years old and 64% of the fishermen have a secondary educational level (high school). They responded that the worst damage is the sea pollution with toxic inputs and recommend that policy makers should develop plans and projects for climate change adaptation (figures 3 and 4).





Source: Prepared by the author.

Figure 3. Climate change damage in the fishing zone

Figure 4. Actions recommended by artisanal fishermen

The El Niño phenomenon related to the increase in SST would generate low productivity with a decrease in the anchoveta resource. It also causes a decrease in primary and secondary production (phyto- and zooplanxton), the main food of anchoveta (PRODUCE, 2016b).

3.2.1. Adaptation Measures Explored for Artisanal Marine Fishing

Diversification of fish caught to include both cold and warm water habitats based on climate variability.

Public policies should be oriented toward the following:

1) Promoting studies on the varieties of fish most vulnerable to extreme marine events such as high salinity of sea water, acidification of the seas and oceans, and compiling a ranked list of the most vulnerable species encountered.

2) Providing accessible loans to artisanal fishers vulnerable to climate variability and change.

Most artisanal fishermen are over 50 years old and do not have access to commercial bank loans in addition to being affected by climate change.

3) Reducing polluting emissions (toxic inputs, caustic soda, ferrous acid) discharged by industrial fisheries into artisanal fishing grounds for direct human consumption.

Fishermen surveyed from the Lima region ask policy makers to decontaminate the sea.

4) Implementing (regional and municipal government of Lima) adaptation projects for artisanal marine fishing in coordination with key sectoral institutions.

5) Introducing a social retirement pension for artisanal fishers who have worked for 35 years, and/or a special retirement regime with a contribution of one percent of the minimum living wage and a maximum monthly contribution of five soles during times of severe climatic variability.

6) Financing of adaptation projects such as cold chain technological innovation for artisanal marine fishery managed by PRODUCE with funding from the National Fishery Development Fund (FONDEPES), among others.

According to Espino and Yamashiro (2012) during the mid 70's and 80's a strong prevalence of high salinity warm waters was observed within 60 nm of the Peruvian coast, determining zooplankton and anchoveta shortage, and abundance of sardines, horse mackerel and mackerel; in contrast, the recovery of anchoveta coincides with the prevalence of cold outcrop waters in the second half of the 80's. Therefore, diversification of marine fisheries according to sea water temperature is an adaptation measure in order to reduce the economic vulnerability of artisanal fishermen.

Barange *et al.* (2018: 6) argue that adaptation to climate change must occur within the multifaceted context of fisheries, with additional measures or actions, some of which will require institutional adaptation. In our view, an institutional adaptation proposal (Huq, 2016) is the implementation of adaptation projects for artisanal marine fishing in coordination with key sector institutions (PRODUCE, FONDEPES). We are in agreement with IPCC, Barange *et al.* (2018) that adaptation strengthens resilience and reduces vulnerability to climate change.

In the Peruvian case, there is a need to strengthen adaptive institutions for coordinated management of marine ecosystems, policy makers should assist artisanal fishers with plans and projects for climate change adaptation and decontamination of the sea.

For Peru (Espino & Yamashiro, 2012) the Southern Oscillation Index is positively correlated with cold water machete landings and inversely with warm water sardine and mackerel, keeping coherence with the Pacific Decadal Oscillation for the sardine case. The Secular Variation of the Pacific (PSV-IOS Variance) indicates that the greater the variability, the greater the landings of hake, horse mackerel and sardine; however, the greater the variability, the lower landings of bonito and anchoveta. For the first adaptation measure in terms of public policy, IMARPE (2019) and the academy should continue studying on fish varieties both the most vulnerable and the most resistant to extreme marine events.

For the Peruvian case, the ENSO Multivariate Index reflects the coupling between the ocean and the atmosphere, it is composed of six variables, pressure at sea level (P), zonal (U) and southern (V) components of surface wind, sea surface temperature (SST), surface air temperature (A) and total sky cover (C). The index indicates positive correlation with sardine, mackerel and horse mackerel; while with machete the correlation is negative.

Likewise, secular oscillations explain the intensities of seasonal (summer-winter) and eventual variations such as ENSO (El Niño-La Niña). The Humboldt Current System is subject to frequent disturbances from ENSO. (Espino and Yamashiro, 2012).

In Peru, the Anomaly of the SST in the El Niño 1 + 2 Region is positively correlated with sardine, hake and mackerel, and negatively correlated with Anchoveta and bonito. Highlights the high significance of the correlation with sardine (Espino and Yamashiro, 2012).

For Colgan (2016:36) green bonds and insurance restructuring are two innovations for adaptation financing, the majority of this type of financing is currently dedicated to climate change mitigation rather than dedicated to adaptation. Although adaptation projects for Anchoveta fishing, both for indirect human consumption and DHC, could be financed by issuing green bonds; financing for the adaptation of artisanal marine fishery would come from the National Fishery Development Fund (FONDEPES) of PRODUCE and the regional government of Lima.

4. CONCLUSIONS

Scientists, based on high-quality long-term observation records, are increasingly demonstrating that extreme events are related to anthropogenic climate change, while future projections point to the declining capacity of the oceans to produce fish.

Average annual artisanal marine fishery landings in the ports of the Lima region accounted for 2.2 percent of all of Peru’s artisanal marine fishing over the period 2004-2017.

It has been found that higher SSTs significantly decrease the volume of marine resources landed at the ports of the Lima region and, therefore, that the SST is negatively related to landings of both artisanal fisheries for direct human consumption and industrial fisheries for indirect human consumption.

The SST was found to influence the Gross Added Value of fishery, significant at five percent. It was found that the higher the SST, the lower fishing effort, and lower fishing value in constant soles. Besides, the positive correlation between anchoveta catch for fishmeal and the added value of fishing is very significant.

Considering the vulnerability of artisanal marine fisheries, the main adaptation measures that should be implemented by public policymakers in the sector are: loans accessible to artisanal fishermen vulnerable to climate variability and change (loans for on-board cooling system equipment on their boats); reduction of toxic emissions discharged by industrial fisheries in artisanal fishing grounds for direct human consumption. Given the variability of the SST and a negative relationship between SST and fishing effort, the greater the effort of anchoveta fishing for fishmeal, the greater the spillage of pollutants into the sea, without the adaptation of public policy; and implementation of adaptation projects and the sea decontamination, partly financed by the issuance of green bonds.

It has been shown that climate change affects the productivity of marine resources and that rising seawater temperature reduces artisanal fishery catches; therefore, policymakers in the fisheries sector, in Peru and around the world, must implement adaptation measures as part of their management of a sustainable marine economy.

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